

APPLICATION UNDER UNITED STATES PATENT LAWS

Atty. Dkt. No. 081468-0305313

Invention: LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

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SPECIFICATION



13281 U.S. PTO

P-0310.020-US

LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of co-pending U.S. Application 10/388,766, filed March 17, 2003 and entitled "LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD," which claims priority from European Application No. 02251933.4, filed March 18, 2002, the entire contents of which are herein incorporated by reference. This application also incorporates by reference U.S. Applications 10/379,999, filed March 6, 2003 and entitled "MASK FOR USE IN LITHOGRAPHY, METHOD OF MAKING A MASK, LITHOGRAPHIC APPARATUS, AND DEVICE MANUFACTURING METHOD," and 10/157,033, filed May 30, 2002 and entitled "LITHOGRAPHIC APPARATUS, DEVICE MANUFACTURING METHOD, DEVICE MANUFACTURED THEREBY, CONTROL SYSTEM, COMPUTER PROGRAM, AND COMPUTER PRODUCT." This application incorporates by reference U.S. Patent 6,583,855, issued June 24, 2003 and entitled "LITHOGRAPHIC APPARATUS, DEVICE MANUFACTURING METHOD, AND DEVICE MANUFACTURED THEREBY."

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates to a lithographic projection apparatus and device manufacturing method.

2. Description of the Related Art

[0003] The term "patterning device" as here employed should be broadly interpreted as referring to device that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate. The term "light valve" can also be used in this context. Generally, the pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). An example of such a patterning device is a mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on

the mask, according to the pattern on the mask. In the case of a mask, the support will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.

[0004] Another example of a patterning device is a programmable mirror array. One example of such an array is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that, for example, addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind. In this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. An alternative embodiment of a programmable mirror array employs a matrix arrangement of tiny mirrors, each of which can be individually tilted about an axis by applying a suitable localized electric field, or by employing piezoelectric actuators. Once again, the mirrors are matrix-addressable, such that addressed mirrors will reflect an incoming radiation beam in a different direction to unaddressed mirrors. In this manner, the reflected beam is patterned according to the addressing pattern of the matrix-addressable mirrors. The required matrix addressing can be performed using suitable electronics. In both of the situations described above, the patterning device can include one or more programmable mirror arrays. More information on mirror arrays as here referred to can be seen, for example, from United States Patents 5,296,891 and 5,523,193, and PCT publications WO 98/38597 and WO 98/33096. In the case of a programmable mirror array, the support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.

[0005] Another example of a patterning device is a programmable LCD array. An example of such a construction is given in U. S. Patent 5,229,872. As above, the support in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

[0006] For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table. However, the general principles discussed in such instances should be seen in the broader context of the patterning device as set forth above.

[0007] Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (IC's). In such a case, the patterning device may generate a circuit pattern

corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. including one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion at once. Such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus, commonly referred to as a step-and-scan apparatus, each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction. Since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be seen, for example, from U.S. Patent 6,046,792.

[0008] In a known manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. It is important to ensure that the overlay (juxtaposition) of the various stacked layers is as accurate as possible. For this purpose, a small reference mark is provided at one or more positions on the wafer, thus defining the origin of a coordinate system on the wafer. Using optical and electronic devices in combination with the substrate holder positioning device (referred to hereinafter as "alignment system"), this mark can then be relocated each time a new layer has to be juxtaposed on an existing layer, and can be used as an alignment reference. Eventually, an array of devices will be present on the substrate (wafer). These devices are then

separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

[0009] For the sake of simplicity, the projection system may hereinafter be referred to as the "lens." However, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Dual stage lithographic apparatus are described, for example, in U.S. Patents 5,969,441 and 6,262,796.

[0010] Correct imaging of a pattern generated by a patterning device in a lithographic projection apparatus requires correct illumination of the patterning device. In particular, it is important that the intensity of illumination proximal the plane of the pattern, as generated by the patterning device, or proximal planes conjugate to the plane of the pattern, be uniform over the area of the exposure field. Also, it is generally required that the patterning device can be illuminated with off-axis illumination in a variety of modes such as, for example, annular, quadrupole or dipole illumination, to improve resolution. The use of such illumination modes is disclosed, for example, in U.S. Patent 6,671,035. The illumination modes are obtained, for example, by providing a corresponding predetermined intensity distribution in a pupil of the illumination system.

[0011] To meet the above-mentioned requirements, the illumination system of a lithographic projection system is generally quite complex. A typical illumination system might include: shutters and attenuators configured to control the intensity of the beam output by the source, which might be a high pressure Hg lamp or an excimer laser; a beam shaping element such as, for example, a beam expander for use with an excimer laser radiation beam configured to lower the radiation beam divergence; a zoomable axicon pair and a zoom lens configured to set

the illumination mode and parameters (collectively referred to as a zoom-axicon); an integrator, such as a quartz rod, configured to make the intensity distribution of the beam more uniform; masking blades configured to define the illumination area; and imaging optics configured to project an image of the exit of the integrator onto the patterning device. For simplicity, the plane of the pattern generated by the patterning device, and planes conjugate to this plane in the illumination system and the projection system may be referred to hereinafter as "image" planes.

[0012] The illumination system may also include elements configured to correct non-uniformities in the illumination beam at or near image planes. For example, the illumination system may include diffractive optical elements to improve the match of the projection beam cross-section proximal the entrance face of the integrator rod with the shape of the entrance face. A diffractive optical element typically includes an array of microlenses, which may be Fresnel lenses or Fresnel zone plates. Improving the match alleviates the problem of field dependent lithographic errors occurring in the patterned layer. The matching may hereinafter be referred to as "filling" of the integrator entrance face. A diffractive optical element may also be positioned, for example, in front of a beam shaping element, such as a zoom-axicon, to transform the angular distribution of radiation provided by an excimer laser beam into a predetermined angular distribution of radiation to generate a desired illumination mode. Illumination systems as discussed above are disclosed, for example, in U.S. Patents 5,675,401 and 6,285,443.

[0013] The illumination system may also include, for example, a filter partially transmissive to radiation of the projection beam with a predetermined spatial distribution of transmittance, immediately before the plane of the pattern, to reduce spatial intensity variations.

[0014] The illumination systems discussed above still suffer from various problems, however. In particular, various elements that are used, especially diffractive optical elements and quartz-rod integrators, can introduce an anomaly of intensity distribution in a plane perpendicular to the optical axis of the radiation system or the projection system. For example, in a plane proximal a pupil of the radiation system or the projection system, either the beam cross-section may be elliptical rather than circular, or the beam intensity distribution within the beam cross-section may, for example, be elliptically symmetric rather than circularly symmetric. Both types of errors are referred to as "ellipticity of the projection beam" or simply as "ellipticity error," and typically lead to specific lithographic errors in the patterned layers. In particular, a patterned feature occurring in directions parallel to both the X and Y direction may exhibit, in the presence of ellipticity of the beam, different sizes upon exposure and processing. Such a lithographic error

is usually referred to as H-V difference. Also, a diffractive optical element used to improve filling of the integrator is generally only optimum for one setting of the zoom-axicon. For other settings, the integrator entrance face may be under-filled (the beam cross-section is smaller than the integrator entrance face), leading to substantial field dependent H-V difference. For other settings, the integrator entrance face may also be over-filled, leading to energy wastage. Additionally, 157 nm excimer lasers and other excimer lasers tend to have large divergence differences in X and Y directions which cannot be completely resolved using beam expander lenses while keeping the shape of the beam within acceptable dimensions.

[0015] Ellipticity errors in the projection beam may also be caused by subsequent elements, such as the mask and elements of the projection system. Current lithographic apparatus do not correct or compensate for ellipticity errors introduced into the projection beam by elements subsequent to the illumination system.

[0016] In a lithographic apparatus, it is important that illumination of the patterning device is uniform in field and angle distribution and, for illumination modes such as dipole and quadrupole illumination, all poles are equal. To achieve this, an integrator is provided in the illumination system. In a lithographic apparatus using UV or DUV exposure radiation the integrator may take the form of a quartz rod or a so-called fly's eye lens. A fly's eye lens is a lens built up of a large number of smaller lenses in an array which creates a correspondingly large number of images of the source in a pupil plane of the illumination system. These images act as a virtual, or secondary, source. However, when using EUV exposure radiation the illumination system must be constructed from mirrors because there is no known material suitable for forming a refractive optical element for EUV radiation. In such an illumination system, a functional equivalent to a fly's eye lens can be provided using faceted mirrors, for instance as described in U.S. Patents 6,195,201, 6,198,793 and 6,452,661. These documents describe a first, or field, faceted mirror which focuses a plurality of images, one per facet, on a second, or pupil, faceted mirror which directs the light to appropriately fill the pupil of the projection system. It is known from UV and DUV lithography that imaging of different types of mask patterns can be improved by controlling the illumination settings, *e.g.* the filling ratio of the pupil of the projection system (commonly referred to as σ) or the provision of special illumination modes such as annular, dipole or quadrupole illumination. More information on illumination settings can be obtained from U.S. Patent 6,452,662 and U.S. Patent 6,671,035.

[0017] In an EUV lithographic apparatus with a fly's eye integrator, these illumination settings can be controlled by selectively blocking certain of the pupil facets. However, because the source position and size on each facet is not exactly known and not stable, it is necessary to block off whole facets at a time, rather than partial facets. Thus, only relatively coarse control of illumination settings is possible. Also, to provide an annular illumination setting it is necessary to obscure the innermost pupil facets and when positioning a masking blade over an inner facet it is difficult to avoid partially obscuring one or more of the outer facets.

[0018] Referring to Figures 14a and 14b, a pupil plane includes a plurality of overlapping pupils. The overlapping pupils produce a field plane. As shown in Figures 14a and 14b, a square field plane is formed by four overlapping cones of radiation in the pupil plane. In the pupil plane, the pupil shape can be corrected for all field positions with transmission filters. The pupil distribution cannot be influenced over the field in a controlled manner. Only a pupil correction that is constant over the field can be applied. In the field plane, the uniformity profile can be changed for all angles with transmission filters. Transmission filters can only change the transmission for all angles.

[0019] In order to make field dependent corrections to the pupil distribution, the correction must take place between the pupil plane and the field plane. The difficulty is that the pupil of one field point overlaps with the pupil of an adjacent field point. In an intermediate plane, the left portion of a pupil corresponding to a right field point overlaps with the right portion of a pupil corresponding to a left field point. Accordingly, it is not possible to correct one portion of the pupil for one field point without affecting the pupil for another field point.

SUMMARY OF THE INVENTION

[0020] According to an exemplary embodiment of the present invention, a lithographic apparatus includes a radiation system configured to provide a beam of radiation. The radiation system includes an illumination system. A support is configured to support a patterning device and the patterning device is configured to pattern the beam of radiation according to a desired pattern. A substrate table is configured to hold a substrate. The apparatus also includes a projection system configured to project the patterned beam of radiation onto a target portion of the substrate; and a device positioned in a first plane intermediate a second plane conjugate to a plane of the substrate and a third plane conjugate to a pupil plane of the projection system. The

device includes a plurality of blades. Each blade is selectively insertable into the beam of radiation.

[0021] According to another aspect of the present invention a device manufacturing method includes providing a substrate at least partially covered by a layer of radiation-sensitive material; providing a beam of radiation using a radiation system, the radiation system including an illumination system; using a patterning device to endow the beam of radiation with a pattern in its cross-section; projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material using a projection system; and selectively inserting at least one blade of a plurality of blades into the beam of radiation in a first plane intermediate a second plane conjugate to a plane of the substrate and a third plane conjugate to a pupil plane of the projection system.

[0022] According to still another aspect of the present invention, a lithographic apparatus includes a radiation system configured to provide a beam of radiation, the radiation system including an illumination system, the illumination system including a field faceted mirror and a pupil faceted mirror. A support is configured to support a patterning device and the patterning device is configured to pattern the beam of radiation according to a desired pattern. A substrate table is configured to hold a substrate and a projection system is configured to project the patterned beam of radiation onto a target portion of the substrate. A plurality of reflective blades are each selectively insertable into the beam of radiation in front of at least one facet of at least one of the field faceted mirror and the pupil faceted mirror to reflect a portion of the beam of radiation to a beam dump.

[0023] According to an even further aspect of the present invention, a device manufacturing method includes providing a substrate at least partially covered by a layer of radiation-sensitive material; providing a beam of radiation using a radiation system, the radiation system including an illumination system, the illumination system including a field faceted mirror and a pupil faceted mirror; using a patterning device to endow the beam of radiation with a pattern in its cross-section; projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material using a projection system; and selectively inserting at least one reflective blade into the beam of radiation in front of at least one facet of at least one of the field faceted mirror and the pupil faceted mirror to reflect a portion of the beam of radiation to a beam dump.

[0024] Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms “reticle”, “wafer” or “die” in this text should be considered as being replaced by the more general terms “mask”, “substrate” and “target portion”, respectively.

[0025] In the present document, the terms “radiation” and “beam” are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (*e.g.* with a wavelength of 365, 248, 193, 157 or 126 nm) and extreme ultra-violet radiation (EUV), *e.g.* having a wavelength in the range 5-20 nm, especially around 13nm, as well as particle beams, such as ion beams or electron beams.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which:

[0027] Figure 1 is a schematic illustration of a lithographic projection apparatus according to an exemplary embodiment of the present invention;

[0028] Figure 2 is a schematic illustration of a lithographic projection apparatus according to an exemplary embodiment of the present invention;

[0029] Figure 3a is a schematic illustration of an illumination system according to an exemplary embodiment of the present invention;

[0030] Figure 3b is a schematic illustration of an illumination system according to another exemplary embodiment of the present invention;

[0031] Figure 4 is a schematic illustration of an ellipticity correction device according to an exemplary embodiment of the present invention;

[0032] Figure 5 is a further schematic illustration of the device of Figure 4;

[0033] Figure 6 is a schematic illustration of a portion of the device of Figures 4 and 5;

[0034] Figures 7a and 7b are perspective and plan view schematic illustrations, respectively, of a radiation beam;

[0035] Figure 8 is a schematic illustration of a device according to another exemplary embodiment of the present invention;

[0036] Figures 9a – 9c are schematic illustrations of the operation of a step and scan lithographic apparatus according to an exemplary embodiment of the present invention;

[0037] Figure 10 is a schematic illustration of an effective or total pupil spot as seen by a wafer in a step and scan lithographic apparatus according to Figures 9a – 9c;

[0038] Figure 11 is a schematic illustration of an illumination system according to an exemplary embodiment of the present invention;

[0039] Figure 12a is a schematic illustration of an illumination system according to an yet another exemplary embodiment of the present invention;

[0040] Figure 12b is a schematic illustration of the illumination system of Figure 12a in a different configuration;

[0041] Figure 13a is a schematic illustration of an illumination system according to a still further exemplary embodiment of the present invention;

[0042] Figure 13b is a schematic illustration of the illumination system of Figure 13a in a different configuration; and

[0043] Figures 14a and 14b are schematic illustrations of a radiation beam of an illumination system of a step and scan lithographic apparatus.

[0044] In the Figures, corresponding reference symbols indicate corresponding parts.

DETAILED DESCRIPTION

[0045] Figure 1 schematically depicts a lithographic projection apparatus 1 according to an embodiment of the invention. The apparatus 1 includes a base plate BP. A illumination system is configured to supply a projection beam PB of radiation (e.g. EUV radiation). A radiation source SO is configured to provide a radiation beam to the illumination system IL. The source SO and the apparatus 1 may be separate, for example when the source is a plasma discharge source. In such case, the source SO is not considered to form part of the apparatus 1 and the radiation beam is generally passed from the source LA to the illumination system IL with the aid of a radiation collector including, for example, suitable collecting mirrors and/or a spectral purity filter. In other cases, the source SO may be integral with the apparatus 1, for example when the source SO is a mercury lamp. The present invention encompasses both of

these scenarios. The source SO and the illumination system IL may be referred to as a radiation system.

[0046] A first object (mask) table MT provided with a mask holder is configured to hold a mask MA (e.g. a reticle), and is connected to a first positioning device PM configured to accurately position the mask with respect to a projection system or lens PL. A second object (substrate) table WT provided with a substrate holder is configured to hold a substrate W (e.g. a resist-coated silicon wafer), and is connected to a second positioning device PW configured to accurately position the substrate with respect to the projection system PL. The projection system or lens PL (e.g. a mirror group) is configured to image an irradiated portion of the mask MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

[0047] As here depicted, the apparatus is of a reflective type (i.e. has a reflective mask). However, in general, it may also be of a transmissive type, for example with a transmissive mask. Alternatively, the apparatus may employ another kind of patterning device, such as a programmable mirror array of a type as referred to above.

[0048] The source SO (e.g. a discharge or laser-produced plasma source) produces a radiation beam. The radiation beam is fed into the illumination system IL, either directly or after having traversed a conditioning device, such as a beam expander Ex, for example. The illumination system IL may include an adjusting device AM that sets the outer and/or inner radial extent (commonly referred to as σ -outer and σ -inner, respectively) of the angular intensity distribution in the radiation beam. In addition, it will generally include various other components, such as an integrator IN and a condenser CO. In this way, the projection beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

[0049] The projection beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having traversed the mask MA, the projection beam PB passes through the lens PL, which focuses the projection beam PB onto a target portion C of the substrate W. With the aid of the second positioning device PW and interferometer IF, the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the beam PB. Similarly, the first positioning device PM can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning),

which are not explicitly depicted in Figure 1. However, in the case of a wafer stepper (as opposed to a step and scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed. The mask MA and the substrate W may be aligned using mask alignment marks M_1 , M_2 and substrate alignment marks P_1 , P_2 .

[0050] The depicted apparatus can be used in two different modes:

[0051] 1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected at once, i.e. a single "flash," onto a target portion C. The substrate table WT is then shifted in the X and/or Y directions so that a different target portion C can be irradiated by the beam PB;

[0052] 2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash." Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g., the Y direction) with a speed v , so that the projection beam PB is caused to scan over a mask image. Concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

[0053] Figure 2 shows the projection apparatus 1 according to an exemplary embodiment including the illumination system IL, the source SO, and the projection system PL. The source SO includes a source collector module or radiation unit 3. The illumination system IL includes an illumination optics unit 4. A radiation system 2 includes the source-collector module or radiation unit 3 and the illumination optics unit 4. The radiation unit 3 is provided with the radiation source SO which may be formed by a discharge plasma. An EUV radiation source may employ a gas or vapor, such as Xe gas or Li vapor in which a very hot plasma may be created to emit radiation in the EUV range of the electromagnetic spectrum. The very hot plasma is created by causing a partially ionized plasma of an electrical discharge to collapse onto the optical axis O. The radiation emitted by radiation source SO is passed from a source chamber 7 into a collector chamber 8 via a gas barrier structure or "foil trap" 9. The gas barrier structure 9 includes a channel structure such as, for example, described in U.S. Patent 6,359,969. The collector chamber 8 includes a radiation collector 10, which may be formed by a grazing incidence collector. Radiation passed by the collector 10 is reflected off a grating spectral filter 11 to be focused in a virtual source point 12 at an aperture in the collector chamber 8. From the collector chamber 8, the radiation beam is directed to the illumination optics unit 4.

[0054] The illumination optics unit 4 includes a field faceted mirror 13 including a plurality of field facets (not shown) and a pupil facet mirror 14 including a plurality of pupil facets 120 (Figures 4 and 5). In the present embodiment, three mirrors 15a, 15b, 15c magnify and shape the beam 16 before it impinges on the mask on the mask table MT. The path of the beam 16 is shown in more detail in Figures 3a and 3b. The mirror 15a may preferably be a toroidal mirror, the mirror 15b may preferably be a spherical mirror, and the mirror 15c may preferably be a grazing incidence mirror. A patterned beam 17 is formed which is imaged in projection system PL via reflective elements 18, 19 onto the wafer on the substrate table WT. More elements than shown may generally be present in illumination optics unit 4 and the projection system PL.

[0055] Referring to Figure 4, there is a position along the beam trajectory between the pupil faceted mirror 14 and the mask where the cross-section of the beam 16 is substantially rectangular. The size of the beam cross-section at this position corresponds to the size of the field facets of mirror 13. The cross-section of the beam at this position is blurred by a convolution with the pupil spot distribution and is thus not in focus with respect to the field plane. As shown in Figures 3a and 3b, the position is after the pupil faceted mirror 14 and in front of one of the mirrors 15a, 15b, or 15c, and preferably relatively close to the field plane compared to the pupil plane. It should be appreciated that an ellipticity correction device 20 may be positioned other than as shown in the exemplary embodiments of Figures 3a and 3b.

[0056] As shown in Figure 4, the position is in front of one of the mirrors 15a, 15b, or 15c and the actual size of the field plane at the position is shown by solid lines 100. The size of the field plane before convolution with the pupil spots 120 is shown by dashed lines 110. The cross-section of the beam at the position is substantially rectangular. Pupil spots 120, including integrated pupil spots 125, are distributed throughout the cross section of the beam at the position. The device 20, including a plurality of adjustable blades 22, 24 is provided at the position. The blades 22, 24 are adjustable by linear actuators 23, 25 (Figure 5) to be inserted into the beam in the Y direction. The position of the device 20 is schematically illustrated in Figure 3a as prior to the mirror 15a in a direction of propagation of the beam, but as discussed above the device 20 may be positioned in front of either mirror 15b or 15c. The device 20 may be positioned anywhere between the pupil faceted mirror 14 and the mask, such as shown in Figure 3b for example, but is preferably positioned relatively close to the field plane in comparison to the pupil plane.

[0057] Referring to Figures 4 and 5, the positions of the blades 22, 24 are adjustable by the linear actuators 23, 25 to be insertable into the beam 16 in the Y direction so that part of the pupil spots 120, 125 are covered. The blades 22, 24 are adjusted so that only those pupil spots 120, 125 that correspond to positions at the edge of the cross section of the beam 16 in the Y direction are covered. The amount of radiation incident under an angle in the Y direction, i.e. the “vertical light,” is decreased in those pupil spots 120, 125 that are covered, wholly or partially. Thus, when a scan is performed the integrated vertical light is less than the “horizontal light,” i.e., the radiation incident under an angle in the X direction. The device 20 corrects or compensates the ellipticity value (the ratio of the vertical light to the horizontal light) of the beam at the position by taking into account the ellipticity error(s) that may be introduced into the beam by subsequent elements of the illumination system, the mask, and/or the projection system. The ellipticity value can be corrected or compensated by decreasing the amount of vertical light only. By absorbing or blocking vertical light at selected positions in the X direction, the total amount of light decreases and the uniformity, i.e. intensity variation over the cross section of the beam, is corrected or compensated. The variation may be corrected by an apparatus such as the one disclosed in U.S. Patent 6,404,499, for example.

[0058] Referring to Figure 5, the device 20 includes partially opaque blades 22 and solid blades 24 connected to respective linear actuators 23 and 25 so as to be selectively and incrementally insertable into the beam in the Y direction. The blades 22 and 24 may also be reflective. The blades may have a reflection profile that varies from completely reflecting to fully absorbing. The blades 22 and 24 are constructed as a plurality of fingers 26 and 27, one of each per column of field or pupil facets that are selectively and incrementally extendible to cover ones of the field or pupil facets. However, it should be appreciated that pairs or groups of fingers may be grouped together.

[0059] The partially opaque fingers may be constructed, for example, as a grid of rods, bars or wires or by forming apertures in a suitable pattern in a solid plate. A partially opaque finger 26 formed with a plurality of rods 29 is shown in Figure 6.

[0060] In general, for other shapes and arrangements of pupil spots, the blades 22 and 24 may be arranged differently. As an alternative to adjustable blades, it is possible to provide a plurality of blades, partially opaque, solid and/or reflecting, corresponding to desired illumination settings and selectively interpose these into the beam 16 as desired. Such fixed blades may be

formed as plates with appropriate openings and partially opaque (apertured) areas and may be held in a magazine or carousel to be inserted into the beam.

[0061] By providing multiple partially opaque blades with different blocking ratios, smaller increments of the pupil filling ratio σ can be provided. For example, with two appropriately aligned partially opaque blades, one blocking 25% and one blocking 50%, quarter steps can be provided. A step is one row or column on the field or pupil facet mirror. For example, by extending the 25% blade one more step than a solid masking blade a quarter step is provided. Extending the 50% blade one step more provides a half step and both the 25% and 50% blade extended one more step provides a three quarter step.

[0062] Referring to Figures 7a and 7b, the field plane and the pupil plane for a beam in a step and scan lithographic apparatus are schematically illustrated. In an intermediate plane, there is a field-like distribution in the X (non-scanning) direction and a pupil-like distribution in the Y (scanning) direction. As in the exemplary embodiment discussed above, it is possible to place a filter at the edges of the intermediate plane in the Y direction. To properly perform a pupil compensation or correction, the compensation or correction must be done relatively far from the field plane. The correction or compensation is preferably performed relatively far from the reticle. In a step and scan apparatus, the beam cross section has a relatively small dimension in the Y (scanning) direction and a relatively larger dimension in the X (non-scanning) direction. The beam cross section is thus pupil-like in the scanning (Y) direction relatively close to the field plane and field-like in the non-scanning (X) direction. The pupil may thus be corrected in the scanning direction by inserting filters having predetermined absorbing patterns into the intermediate plane in the scanning (Y) direction.

[0063] Referring to Figure 8, blades or plates 28 having predetermined transmissibility/absorbing patterns are insertable in the Y direction into the edges of the intermediate plane to correct the ellipticity value. The blades 28 are insertable and adjustable by linear actuators 21, similar to the embodiment described above. The transmissibility/absorbing pattern of the blades 28 may be formed to provide a predetermined field dependence to the device 20A. As shown, the pattern of the blades 28 varies in the non-scanning (X) direction and thus the correction or compensation can vary in the non-scanning direction.

[0064] Referring to Figures 9a-c, in a step and scan lithographic apparatus 1, the pupil P as seen on the substrate W changes during a scan. The illuminated area IA is defined as a sharp image of a quartz rod integrator (discussed in more detail below). Figure 9a schematically

illustrates the pupil P1 as seen by the substrate W immediately after the beginning of a scan. Figure 9b schematically illustrates the pupil P2 as seen by the substrate W in the middle of a scan. Figure 9c schematically illustrates the pupil P3 as seen by the substrate W immediately prior to the end of a scan. Although the step and scan apparatus illustrated in Figures 9a-c uses a transmissive mask, it should be appreciated that the present invention also contemplates the use of reflective masks.

[0065] Referring to Figure 10, the sum of all the static pupils P1-P3 seen by the substrate results in the effective or scanning pupil P. Although three static pupils P1-P3 are schematically illustrated, it should be appreciated that during a scan a significantly larger number of static pupils are summed to produce the effective or scanning pupil.

[0066] Referring to Figure 11, an illumination system IL according to another exemplary embodiment of the present invention includes a radiation source SO, for example a high pressure Hg lamp provided with an elliptical reflector to collect the output radiation or a laser. Two shutters are provided to control the output of the lamp: a safety shutter 111 held open by a coil 111a and arranged to close automatically if any of the panels of a casing of the lithographic apparatus are opened. A rotary shutter 112 is driven by a motor 112a for each exposure. A second rotary shutter 113 is driven by a motor 113a and a light attenuating filter in the shutter aperture may be provided for low-dose exposures.

[0067] Beam shaping is principally performed by an axicon 115 and zoom lens 116, which are adjustable optical elements driven by respective servo systems 115a, 116a. These components are referred to collectively as the zoom-axicon. The axicon 115 includes a concave conical lens and complementary convex conical lens whose separation is adjustable. Setting the two elements of the axicon 115 together provides conventional circular illumination, while moving them apart creates an annular illumination distribution.

[0068] The zoom lens 116 determines the size of the beam or the outer radius of an annular illumination mode. A pupil shaping device (not shown) may be inserted, for instance, in the exit pupil 122 of the zoom-axicon module to provide quadrupole or other illumination modes. Coupling optics couple the light from the zoom-axicon into an integrator IN.

[0069] The integrator IN includes, for example two elongate quartz rods 117 joined at a right-angle prism 117a, the hypotenuse surface of which is partially silvered to allow a small, known proportion of the beam energy through to an energy sensor ES. The beam undergoes multiple internal reflections in the quartz rods 117 so that, looking back through it, there is seen a

plurality of spaced apart virtual sources, thus evening out the intensity distribution of the beam. It should be appreciated that a fly's eye lens could be used as the integrator.

[0070] After the exit of the integrator IN the device 20A is positioned to correct or compensate for the ellipticity value of the illumination area IA, i.e. the area of the reticle to be illuminated. The condensing optics CO form an objective lens for imaging the masking orifice, via an intermediate pupil 123, on the mask MA. A folding mirror 220 is included for convenient location of the illumination system in the apparatus.

[0071] According to another exemplary embodiment of the present invention, the pupil filling ratio σ may be controlled by providing adjustable, reflective coated blades in the illumination system. This exemplary embodiment is useful in lithographic apparatus using EUV radiation as blades which absorb radiation, such as those disclosed in U.S. Application 10/388,766, will experience a significant heat load which may adversely affect the performance of the faceted mirrors used in EUV illumination systems and other optical elements.

[0072] Referring to Figures 12a and 12b, the illumination system includes blade mirrors BM selectively insertable or positionable in front of facets of the field faceted mirror 13. The blade mirrors BM are coated to be reflective. The coating may include a surface roughness so that the reflected radiation is scattered. Such a coating is disclosed in U.S. Application 10/379,999, incorporated herein by reference. The coating may also include a phase changing structure so that the reflected radiation from individual blade mirrors cancel each other. Such a coating including a phase changing structure is disclosed in U.S. Application 10/379,999.

[0073] The radiation reflected by the blade mirrors BM is directed to a beam dump BD which may be cooled to prevent adverse effects on the performance of the apparatus.

[0074] Referring to Figures 13a and 13b, an illumination system according to another exemplary embodiment of the present invention includes blade mirrors BM selectively insertable or positionable in front of facets of the pupil faceted mirror 14. The blade mirrors BM are coated so as to be reflective. The coating may include a surface roughness such that the reflected radiation is scattered or may include a phase changing structure so that the reflected radiation from individual blade mirrors cancel each other, as discussed above. The radiation reflected by the blade mirrors BM is directed to a beam dump BD which may be cooled to prevent adverse effects on the performance of the apparatus. As the pupil facets are smaller than the field facets, the pupil spots reflected by the blade mirrors of Figures 13a and 13b are smaller than the field

facets reflected by the blade mirrors of Figures 12a and 12b, thus a smaller beam dump may be used.

[0075] Although the embodiments shown in Figures 12a and 12b and 13a and 13b describe the blade mirrors as inserted or positioned in front of the field faceted mirror and the pupil faceted mirror, respectively, it should be appreciated that blade mirrors may be placed in front of both the field faceted mirror and the pupil faceted mirror. It should also be appreciated that the various exemplary embodiments may be used in combination. For example, the devices shown in Figures 3a-6, 8 and 11 may be used in combination with the embodiments shown in Figures 12a-13a.

[0076] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.